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Determining Benefits and Costs of Improved Central Air Conditioner Efficiencies

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ABSTRACT

Economic impacts on individual consumers from possible revisions to U.S. residential-type central air conditioner energy-efficiency standards are examined using a life-cycle cost (LCC) analysis. LCC is the consumer's cost of purchasing and installing a central air conditioner and operating it over its lifetime. This approach makes it possible to evaluate the economic impacts on individual consumers from the revised standards. The methodology allows an examination of groups of the population which benefit or lose from suggested efficiency standards. The results show that the economic benefits to consumers due to modest increases in efficiency are significant. For an efficiency increase of 20% over the existing minimum standard (i.e., 12 SEER), 35% of households with central air conditioners experience significant LCC savings, with an average savings of $453, while 25% show significant LCC losses, with an average loss of $158. The remainder of the population (40%) are largely unaffected.

PROBLEM

Policy decisions involve assessments of benefits and costs. However, questions such as what level of benefit is significant and at what point do costs become important are not universally agreed upon. A method to determine the benefits and costs of one type of policy decision and ways to interpret the results of the analysis are discussed in this paper.

This benefit and cost study grows out of work done for the U.S. Department of Energy (DOE).[1] Federal law sets energy conservation standards for various consumer products and directs DOE to create or amend energy standards for major household appliances. Any new or amended standard must achieve the maximum improvement in energy efficiency that is technologically feasible and economically justified. This study presents the overall approach used in the LCC analysis and illustrates it with results for residential-type split system central air conditioners.*

APPROACH: DETERMINING CONSUMER BENEFITS AND COSTS

Economic impacts on individual consumers from possible revisions to U.S. residential-type central air conditioner energy-efficiency standards are examined using a life-cycle cost (LCC) analysis. LCC is the total cost a consumer pays during the lifetime of a central air conditioners, including purchase price and operating expenses (which cover energy expenditures and any maintenance costs). Future operating expenses are discounted to the time of purchase and summed over the central air conditioner's lifetime. The effect of standards is a change in the operating expense (usually decreased) and a change in the purchase price (usually increased). The net effect is analyzed by calculating the change in LCC as compared to the base case. Inputs to the LCC calculation include the installed consumer cost (purchase price plus

* Residential-type central air conditioners are air-cooled systems that are powered by single phase electric current and are rated below 65,000 Btu/hr in cooling capacity. Split systems account for approximately 90% of central air conditioner shipments.

installation cost), operating expenses (energy and maintenance costs), lifetime of the appliance, and a discount rate.

LCC is defined by the following equation:

$$LCC = EquipCost + NPV(D_{rate}, OprCost_{year}, Lifetime)$$

EquipCost (Equipment Cost) is the cost ($) of buying and installing a central air conditioner. This includes the cost of the central air conditioners plus sales tax, installation charges, and, if the central air conditioner is being replaced, charges to remove the old central air conditioner.

NPV (Net Present Value ($)) is the present value of a future stream of expenditures or earnings and is defined by the following equation:

$$NPV = \sum_{year=1}^{Lifetime} \frac{OprCost_{year}}{(1 + D_{rate})^{year}}$$

D_{rate} (Discount rate (%)) is defined as the rate at which future expenditures are discounted to establish their present value. For this study, it is the consumer's interest rate minus inflation.

OprCost (Operating Cost) is defined as the annual expense to keep a central air conditioner operating. It has three parts: energy, repair, and maintenance. Energy costs are calculated by multiplying annual central air conditioner energy use by the energy price paid by the household. Repair costs are costs to the consumer for replacing or repairing components which have failed in the equipment. Maintenance costs are the costs to the consumer of maintaining equipment operation such as checking and maintaining refrigerant charge levels and cleaning heat exchanger coils.

Lifetime is the length of time the central air conditioner will provide service.

At this point, the benefits and costs to the consumers can be defined as net changes in LCC when comparing various design options to the baseline:

$$\Delta LCC = LCC_{base} - LCC_{design}$$

where LCC_{base} refers to a typical future central air conditioner in the absence of new efficiency standards and LCC_{design} is a future higher efficiency unit, given standards.

If ΔLCC is less than 0, then there is a net cost to the consumer and if it is greater than 0, it indicates a benefit (net savings) to the consumer. Using this calculation, it is possible to determine the fractions of the population that benefit or are disadvantaged by efficiency standards.

Baseline and Efficiency Levels

The overall analysis considers four central air conditioner efficiency levels beyond the baseline level. Central air conditioners are rated with a seasonal energy efficiency ratio (SEER) which is the amount of heat removed during a cooling season in Btu's divided by the total electrical energy input in watt-hours during the same period. The baseline level represents central air conditioners that just meet the existing minimum efficiency standard (10 SEER). The efficiency levels considered are 11, 12, and 13 SEER as well as a maximum technologically feasible efficiency level of 18 SEER.

Key Input Variables

The major input variables used in the central air conditioner LCC analysis are equipment price, energy consumption, energy price, discount rate, and central air conditioner lifetime. All of these variables are expressed as distributions, which represent a range of reported or expected values. Several distribution types are used in this analysis. Triangular distributions are used when minimum, most-likely, and maximum values are available. When only a mean and variance about a random variable are known, a normal distribution is used to describe the variable. When only minimum and maximum are known, a uniform distribution is used. Custom distributions are used when series of actual data were known. With the exception of equipment prices, all of the above input variables are characterized with custom distributions derived from actual data. Equipment prices are derived from a variety of input variables that are characterized with either single-point values (for estimates of manufacturing costs) or different types of distributions (e.g., normal distributions for distributor and dealer markups, a uniform distribution for the builder markup, and custom distributions for the manufacturer markup and sales taxes).

Although only residential-type central air conditioners are considered in this analysis, a significant percentage of these systems are used in small commercial buildings. As a result, the analysis takes into account equipment use in commercial buildings based on the assumption that 10 percent of equipment applications are in these building types.

For equipment used in residential buildings, some of the input variables are obtained from DOE's Energy Information Administration (EIA) *Residential Energy Consumption Survey* (RECS) for 1997, which contains data from a representative sample of U.S. residential households.[2] For commercial buildings, a representative building sample was developed based on assumptions consistent with the process to update ASHRAE Standard 90.1, *Energy Efficient Design of New Buildings Except Low-Rise Residential Buildings*.[3] In updating ASHRAE 90.1, 77 nationally representative commercial buildings (consisting of seven different commercial building types in eleven different regions of the country) were developed. The weighting given to each building (i.e., the percentage each building represents of the commercial building stock) were based on data from the 1992 and 1995 Commercial Building Energy Consumption Survey (CBECS).[4,5]

Equipment Price

The basis for developing consumer equipment prices relied on a reverse engineering analysis conducted by Arthur D. Little (ADL) to estimate the manufacturing costs associated with the baseline and various higher efficiency levels. Manufacturing costs were converted to consumer equipment prices by applying a series of markups and sales taxes. The markups included those for the manufacturer, distributor, dealer/contractor, and, for equipment purchased for new construction, the builder.

For residential-type split system central air conditioners, the reverse engineering analysis established an average baseline manufacturing cost of $394. Through the use of manufacturer cost multipliers (i.e., multiplicative values to convert the baseline manufacturing cost into manufacturing costs for the various efficiency levels), most-likely manufacturing costs of $441, $505, $568, and $784 were established for efficiency levels of 11, 12, 13, and 18 SEER, respectively. After application of the markups and sales taxes, the above most-likely manufacturing costs were converted into average consumer equipment prices of $957 for the baseline level and $1,048, $1,170, $1,292, and $1,711 for the 11, 12, 13, and 18 SEER efficiency levels.

Energy Consumption

For purposes of determining residential energy consumption, the RECS data set was utilized. RECS provides a sample of 5,900 households from the population of all primary, occupied residential housing units in the U.S. Of these, 1,218 household records were used in the analysis, representing 23,420,428 actual households. Each household record explicitly provides the energy consumption required to space-cool the home. An additional 308 household records representing 6,271,340 households with central air-conditioning heat pumps were analyzed in a parallel study, reported elsewhere.

The energy consumption associated with each of the 77 commercial buildings were determined through computer simulation modeling conducted by Pacific Northwest National Laboratory (PNNL) using the Building Loads and Systems Thermodynamics (BLAST) simulation tool.[6] The procedure for calculating space-cooling energy consumption relied on the determination of full-load equivalent operating hours (FLEOH) for each of the 77 buildings. Once the FLEOHs were determined, the corresponding annual energy consumption was established using the calculation procedure specified in the Department of Energy's (DOE) test procedure for determining annual energy use assuming a cooling capacity of 36,000 Btu/hr.

Marginal Energy Prices

Marginal energy prices are those prices consumers pay (or save) for the last unit of energy used (or saved). Residential consumer marginal electricity prices for this analysis were estimated directly from household data in the 1997 RECS public use data survey as the change in household monthly energy bill divided by the change in monthly energy consumption. This provides a marginal energy price rate based on actual household bills. LBNL calculated the slope of the regression line for four summer months (June-September) and, separately, for the eight winter (October-May) months. The annual marginal price is the weighted average of the two seasonal prices, where the weighting used the relative energy consumption in each season.[7] The weighting of the seasonal prices were based on simulated cooling and heating loads which were a function of the household's age and geographic location.

Commercial electricity prices were estimated by matching each commercial building's simulated air-conditioning load and demand to actual modeled commercial tariffs. Customer energy bills were then calculated for the building. The energy bill (in dollars) was divided by the energy consumption (in kWh) to come up with an average electricity price (in $/kWh). In the case of developing marginal electricity prices, energy bills were calculated for both the baseline case (i.e., 10 SEER) and a standards case. The difference in the energy bills (in dollars)was divided by the usage difference (in kWh) to give a "marginal" rate of $/kWh for the increment of space-cooling energy saved.

Future Energy Prices

Future electricity costs will vary from building to building. Two primary factors contribute to this variation. One is the existing variability in energy prices, which depend on the rate schedule of the local utility and the consumption pattern of the particular household. The other is the uncertainty of future energy prices, which is further complicated by the current restructuring of the electric supply industry.

Price trends from EIA's *Annual Energy Outlook 2000* (AEO2000) were used to scale the distribution of marginal energy prices for future years.[8] Given the uncertainty of projections of future energy prices, the LCC analysis used a scenario approach to examine the robustness of proposed energy-efficiency standards under different energy price conditions. The AEO2000 Reference Case provides the base scenario. For the high and low energy price scenarios, other scenarios from AEO2000 were used.

Discount Rate

A distribution of discount rates represents the variability in financing methods consumers use in purchasing appliances. Consumers purchase central air conditioners through several finance methods.

For equipment financed through the purchase of a new home, a second mortgage, or a home equity line of credit, the interest rate associated with the finance method is used to establish the discount rate. But for equipment purchased to replace old or failed equipment where cash or some form of credit is used to finance the acquisition, the discount rate is based on how the purchase affects a consumer's overall household financial situation. For example, even though the purchase might be financed through a dealer loan or some other short-term financing vehicle, the more probable effect of the purchase is to either cause the consumer to incur additional credit card debt or forego investment in some type of savings-related asset. As indicated by the Air Conditioning, Heating, and Refrigeration News, 34% of central air conditioner shipments went to new homes.[9] The 1998 Survey of Consumer Finances (SCF) was used to establish the finance methods associated with the remaining 66% of shipments.[10] The 1998 SCF indicated that 21% of shipments are purchased through second mortgages, 2% with credit cards, and 43% through finance methods that eventually are drawn from some type of financial asset (i.e., savings/checking accounts, certificates of deposit, savings bonds, bonds, mutual funds, or stocks).

Lifetime

Central air conditioner lifetime was based on a 1986 survey performed for the Electric Power Research Institute of 2,184 heat pump installations in a seven-state region of the United States. The survey indicated that air conditioners can last up to 24 years with an average lifetime of 18.4 years. For this analysis, a retirement function developed from the heat pump survey was used to represent equipment lifetime.[11]

The heat pump survey also indicated that essentially all heat pump owners replace their original compressor once in the lifetime of system. Thus, in accordance with the survey data, it was assumed the compressor was replaced in the 14th year of the system's life. Because more efficient systems tend to use more efficient and, thus, more expensive compressors, the compressor replacement cost was assumed to increase as system efficiency increases.

Uncertainty and Variability

To account for uncertainty and variability, the LCC model was developed using a spreadsheet combined with a commercially available software that provides risk analysis capabilities. The model uses a Monte Carlo simulation to account for uncertainty and variability of input values. The model accepts ranges (distributions of values) as input for each variable and performs the calculations thousands of times to determine a distribution of the outputs. This distribution reflects the probability of the values that would occur.

When making observations of past events or speculating about the future, imperfect knowledge—uncertainty—is the rule rather than the exception. For example, the energy actually consumed by a central air conditioner has seldom been directly recorded. Rather, energy consumption is usually estimated based on information from industry and government sources. Even direct laboratory measurements have some margin of error. When estimating numerical values expected for quantities at some future date, the exact outcome is rarely known in advance.

Variability means that different applications or situations produce different numerical values for a quantity. Specifying a value for a quantity may be made even more difficult if the value depends on a number of other factors. For example, the energy consumed to air condition a household depends on the household characteristics (e.g., building shell characteristics and occupant behavior) and geographic location (i.e., climate). Surveys can be helpful here, and analysis of surveys can relate the variable of interest (e.g., energy required to air condition) to other variables that are better known or easier to forecast (e.g., occupant behavior and climate).

LCC Spreadsheet

The LCC analysis uses a spreadsheet-based calculation methodology. A weighted random selection of RECS households with central air conditioners and the 77 representative commercial buildings is sampled 10,000 times.

The spreadsheet contains several worksheets for calculating the LCC. The primary worksheet allows the user to interact directly with the spreadsheet to specify the efficiency level to analyze, the energy price projection, and the start year (i.e., the effective date) of the standard. The primary worksheet also summarizes the selections for the primary inputs to the spreadsheet (e.g., energy price, lifetime, discount rate, equipment price) and provides the LCC and payback period for the current sample (i.e., building) being analyzed. It is from the primary worksheet where the user initiates the Monte Carlo simulation for conducting the LCC analysis on the 10,000 sampled buildings. There are nine other worksheets which contain the input data necessary to calculate the LCC. Complete instructions on how to use the spreadsheet are found on an "instructions" worksheet within the spreadsheet. The spreadsheet can be downloaded from the U.S. Department of Energy's web site pertaining to residential central air conditioners.

RESULTS

To evaluate the economic impact on consumers, an LCC analysis was conducted for each of four efficiency levels (i.e., 11, 12, 13, and 18 SEER). This includes an estimation of the percent of the population that would realize reduced LCC from each efficiency level.

The results are presented in Table 1 and Figure 1. Table 1 lists the portion of the population that has any savings or costs, in terms of life-cycle cost, from each efficiency level. For each efficiency level, the table shows the average and maximum possible savings for that fraction of the population benefitting; it also shows the average and maximum costs for the disadvantaged fraction of the population. The middle row lists the percent of the population encountering insignificant (up to 2%) savings or cost.

Figure 1 presents a summary of the life-cycle cost information by percent of the population experiencing net savings or costs. Each bar refers to a specific efficiency level. The bar's height above the zero horizontal axis shows the percentage of households that have a life-cycle savings. Conversely, the portion of the bar below the 0 % horizontal axis show the percentage of households that have a life-cycle net cost. The bars show a greater fraction of the population having netsavings for the first two efficiency levels (i.e., 11 and 12 SEER). As the efficiency levels increase in energy efficiency and cost, the energy savings are not sufficient to offset the higher initial costs and the net effect is a reduction in the percent of households benefitting. The positive and negative portions of the bars are shaded to show three ranges: significant savings, significant costs, and no significant impact. The average baseline life-cycle cost is included as a reference point to indicate the magnitude of the estimated savings or costs.

DISCUSSION OF RESULTS

Table 1 and Figure 1 show the overall distribution of LCC net costs and savings for central air conditioners with different efficiency levels. Table 2 summarizes, in terms of net costs/savings, the affect on consumers of the 12 SEER efficiency level. It shows the percent of the total population which would experience net costs (49.3%) and those with savings (50.7%) and compares them to the percent who will experience net costs/savings larger than 2% (24.6% and 34.8%, respectively) of the average baseline LCC ($5,170). The values in parentheses indicate the actual dollar amounts of the thresholds.

For this design option, the analysis predicts that 49% of consumers would experience some net cost with the more efficient central air conditioner. However, it is reasonable to assume that there are LCC costs or savings so small that consumers would be unable to distinguish them in their annual expenses. Plus or minus 2% of average baseline LCC is chosen as the band of no consumer impact.[1] Removing this segment of the population makes it possible to clearly show the *significant* net savings and net costs associated with any design option. This allows for a more informed weighting of benefits and burdens on consumers.

Table 1 Percent of Population Having Net Savings or Costs for Central AC

Population		Efficiency Level			
		11 SEER	**12 SEER**	**13 SEER**	**18 SEER**
Significant Savings	% of sample	28%	35%	34%	25%
	Average Savings	$305	$453	$589	$1045
	Maximum Savings	$2060	$4382	$4372	$9321
Insignificant Savings or Cost	% of sample	70%	40%	27%	7%
Significant Cost	% of sample	2%	25%	39%	68%
	Average Cost	$118	$158	$217	$584
	Maximum Cost	$168	$344	$530	$1840
Total (100%)	Average Savings	$75	$113	$113	-$137

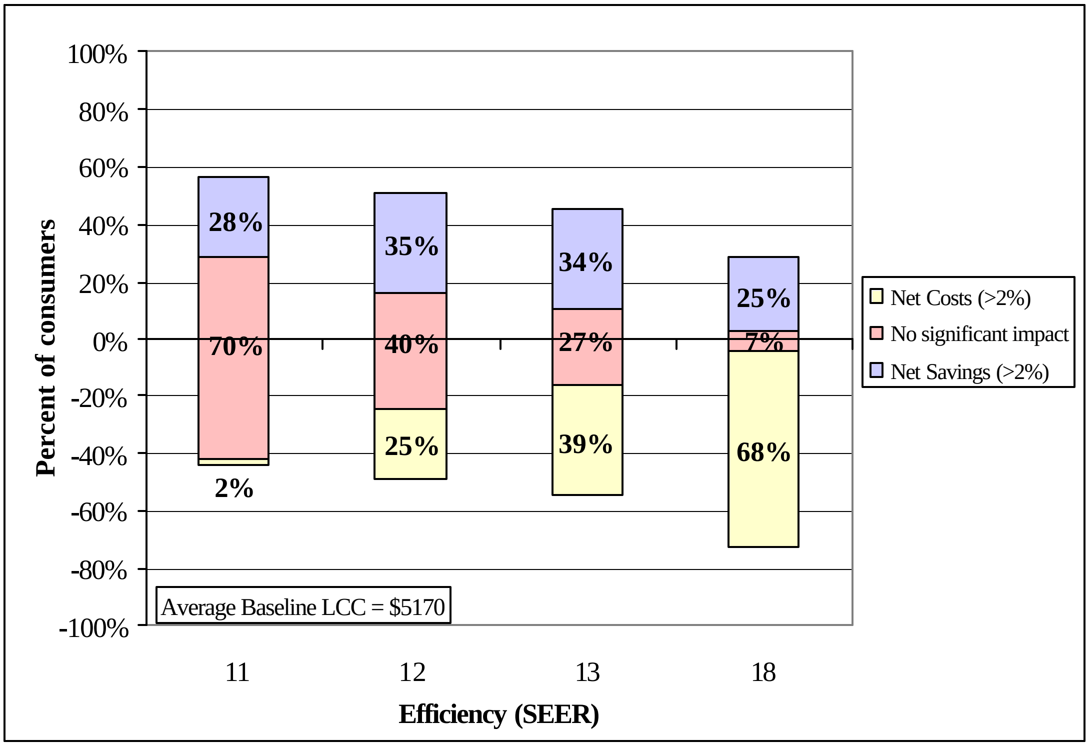

Figure 1 Percent of Sample With Net Savings or Costs for Central Air Conditioners

Table 2 Percent of Population Having Net Cost/Saving

	≥ 2% ($103)	≥ 0% ($0)
Net Cost	24.6%	49.3%
Net Savings	34.8%	50.7%

To illustrate the ±2% assumption, consider the average baseline LCC for central air conditioners of $5,170; 2% of average baseline LCC equals $103. Over the average life of 18.4 years for a central air conditioner this amounts to less than $6 per year. Obviously, this is such a small amount in terms of yearly expenditures that it will not impact consumers' pocketbooks nor their purchase decisions about central air conditioners. This leaves, therefore, only 24.6% of consumers, who will sustain any significant net costs in the case of the 12 SEER efficiency level.

The results for the 11 and 12 SEER efficiency levels show that a small portion of the population will experience a significant cost. The situation is different for the 13 SEER and 18 SEER efficiency levels, for which 54% and 69% of consumers, respectively, have a net cost.

CONCLUSIONS

This LCC analytic approach makes it possible to evaluate the economic impacts on individual consumers of revised U.S. residential central air conditioner energy-efficiency standards. The method permits an examination of groups of the population to determine how many may experience net savings (or costs) from possible efficiency standards.

The sample shows that the economic benefits to consumers are significant. For the 12 SEER efficiency level considered above, the average LCC savings for the 35% of consumers with significant savings is $453 while the 25% of consumers experiencing significant net costs realize average increased costs of $158. The results for heat pumps, which are not discussed in this paper, show an greater magnitude of savings. In many cases, the benefits to the society in energy savings greatly outweigh the encountered costs.

Based on this analysis, the Department of Energy chose a 12 SEER efficiency level for the proposed rule for new efficiency standards for central air conditioners.[12]

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REFERENCES

1. U.S. Department of Energy-Office of Building Research and Standards, *Technical Support Document: Energy Efficient Standards for Consumer Products: Residential Central Air Conditioners and Heat Pumps*, 2000. Washington, D.C. <http://www.eren.doe.gov/buildings/codes_standards/applbrf/central_air_conditioner.html>

2. U.S. Department of Energy-Energy Information Administration, *A Look at Residential Energy Consumption in 1997*, 1999. Washington, DC. Report No. DOE/EIA-0632(97).

3. American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., *Energy Efficient Design of New Buildings Except Low-Rise Residential Buildings*, 1999. Atlanta, GA. Standard 90.1-1999.

4. U.S. Department of Energy-Energy Information Administration, *1992 Commercial Building Energy Consumption and Expenditures (CBECS)*, 1992. Public Use Data, Micro-data file on EIA website:<ftp://ftp.eia.doe.gov/pub/consumption/commercial/micro.data/>

5. U.S. Department of Energy-Energy Information Administration, *1995 Commercial Building*

Energy Consumption and Expenditures (CBECS), 1995. Public Use Data, Micro-data file on EIA website: <http://www.eia.doe.gov/emeu/cbecs/microdat.html>

6. Pacific Northwest National Laboratory, *Screening Analysis for EPACT-Covered Commercial HVAC and Water-Heating Equipment*, 2000. Richland, WA. Report No. PNNL-13232.

7. U.S. Department of Energy, *Draft Marginal Energy Prices Report*, July, 1999. Washington, DC. (Last accessed September 20, 1999). <http://www.eren.doe.gov/buildings/codes_standards/applbrf/pdfs/marginal_energy_price.pdf>

8. U.S. Department of Energy-Energy Information Administration, *Annual Energy Outlook 2000*, December, 1999. Washington, DC. Report No. DOE/EIA-0383(2000).

9. *Air Conditioning, Heating, and Refrigeration News*, December, 12, 1998.

10. The Federal Reserve Board, *1998 Survey of Consumer Finances*, 1998. <http://www.federalreserve.gov/pubs/oss/oss2/98/scf98home.html>

11. Bucher, M.E., C.M. Grastataro, and W.R. Coleman, Heat Pump Life and Compressor Longevity in Diverse Climates. *ASHRAE Transactions*, 1990. 96(1): p. 1567-1571.

12. U.S. Department of Energy-Office of Conservation and Renewable Energy, Energy Conservation Program for Consumer Products: Central Air Conditioners and Heat Pumps Energy Conservation Standards; Proposed Rule. *Federal Register*, 2000. 65(194): p. 59590-59632, October 5.